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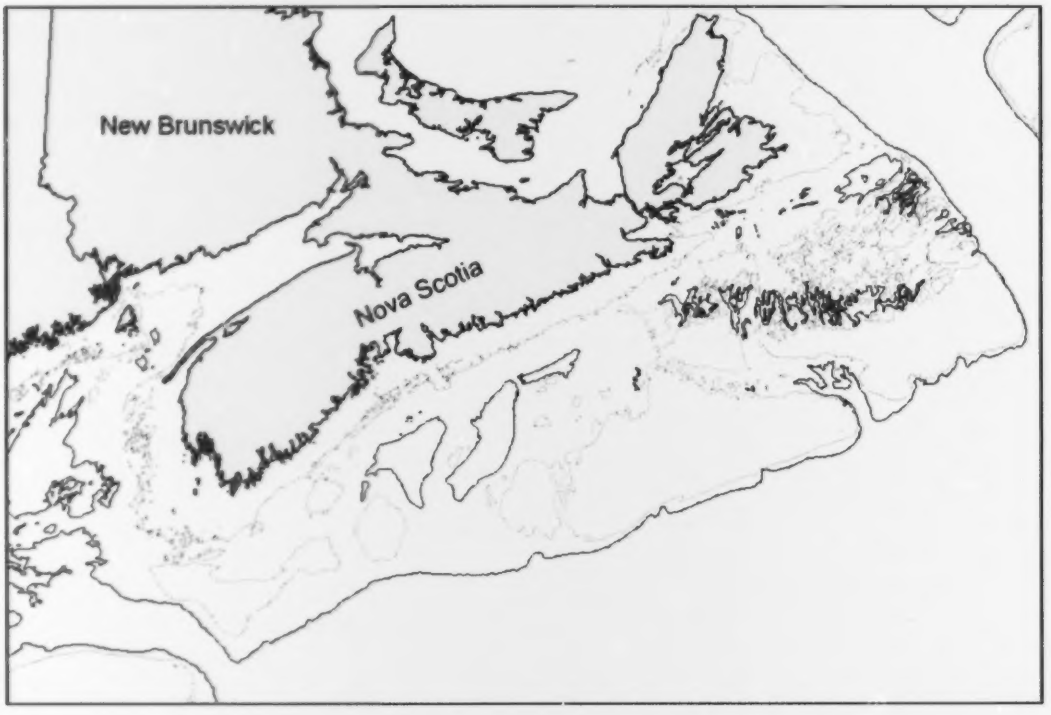
Maritimes Region
Canadian Science Advisory Secretariat
Science Advisory Report 2005/071

FRAMEWORK FOR CLASSIFICATION AND CHARACTERIZATION OF SCOTIA-FUNDY BENTHIC HABITATS



Context

Since Canada's Oceans Act was passed in 1997, Fisheries and Oceans Canada (DFO) has undertaken various initiatives to implement ecosystem-based management in Canada. The Eastern Scotian Shelf Integrated Management (ESSIM) Initiative was one of the first in Canada. It is a collaborative ocean management and planning process that aims to develop and implement an integrated ocean management plan for this large marine area. The plan will provide long-term direction and a common basis for management. A draft ESSIM plan was released in early 2005 (DFO, 2005).

Implementing integrated, ecosystem-based management has required the development of new types of information and new analyses of existing information. In June 2000, a DFO workshop on ecosystem considerations for the ESSIM Initiative was held. It was recommended that benthic ecosystem types should be mapped within the ESSIM area to assist ecosystem-based management. Further guidance was provided by a National DFO Workshop on Objectives and Indicators for Ecosystem-Based Management, which established national conservation objectives for marine ecosystems (described in DFO, 2004a), including:

- *To maintain communities within the bounds of natural variability.*
- *To conserve critical bottomscape features.*

It was agreed that a series of regional advisory process (RAP) meetings would be held to develop a benthic classification scheme for the Scotia-Fundy area (phase I); to test and validate the scheme and

Canada

apply it to the area (phase II); and to assess the sensitivity of the environments classified under the scheme to human activities occurring on the Scotian Shelf (phase III). The RAP would provide advice to management in order to assist in meeting the objective of maintaining the diversity of benthic communities in the Scotia-Fundy area of the Maritimes Region.

Phase I was addressed at a RAP meeting held 25 - 26 June 2001 (DFO, 2002) in which various classification approaches were discussed and recommendations made. Phase II was initiated with a RAP meeting 6 – 8 January 2004 (DFO, 2004b) to review a proposed benthic classification for the Scotia-Fundy Region, followed by a workshop 7 - 9 December 2004 to investigate specific elements of the proposed classification (DFO, 2004c). This report summarizes the benthic habitat classification model presented at the final RAP meeting of phase II held 20 – 22 July 2005.

SUMMARY

- Benthic habitats across the Scotia-Fundy Region can be classified in terms of their exposure to mechanical disturbance of the sediment (*Disturbance*) and the severity of environmental conditions (*Scope for Growth*).
- For the offshore environment of the Scotia-Fundy Region, natural disturbance can be described as the ratio of the frictional velocity on the seabed and the critical shear stress for a given particle size.
- For the offshore environment of the Scotia-Fundy Region, scope for growth of benthic communities can be described by some combination of food availability to the benthos, annual bottom temperature, seasonal and interannual temperature variability, and oxygen saturation. At present, the relative importance of these variables is not clearly understood.
- Sensitivity of benthic organisms can be described as a function of their vulnerability and recoverability. Vulnerability is related to the condition and properties of an organism, including body shape, size and structure, which may influence its susceptibility to impact. Recoverability refers to the rate at which an organism is able to return to some previous state after being impacted.
- The sensitivity of benthic communities and habitats is more complex to describe than the sensitivity of individuals or species.
- Our ability to describe the sensitivity of benthic habitats in the Scotia-Fundy Region may be enhanced through further investigation of the relationship between disturbance / scope for growth and vulnerability / recoverability.
- This framework for the classification and characterization of benthic habitats should be used as one tool in a suite of tools used in ocean planning and management.
- While this benthic classification framework does not specify the precise distribution of benthic communities across the Scotia-Fundy Region, it provides a systematic view of expected life history traits and community structures.

DESCRIPTION OF THE ISSUE

There are a number of human activities (e.g. fishing, petroleum exploration, laying of pipelines and cables) that impact marine benthic communities. Identification of benthic communities and seabed features that are sensitive to human disturbance would help to focus management

activity and ensure that national conservation objectives are being met. While terrestrial mapping and habitat characterization have been aided by the use of satellite and aerial photo imagery and supported by a long history of ecological studies, characterization of marine benthic communities has been hindered by both technological and theoretical limitations. Recent decades have produced technological advances in acoustic mapping of the seafloor using high-resolution multibeam sonars, which yield georeferenced, three dimensional depiction of seabed morphology. However, resource restrictions currently inhibit use of these tools across large areas like the Scotian Shelf. In addition to technological gaps, there have also been gaps in the theoretical understanding of seabed ecosystems and processes. Where knowledge exists, it has not been summarized in a comprehensive manner which is readily applicable for management purposes. This framework for benthic habitat characterization provides a basis for benthic habitat classification, sensitivity characterization, and management in the Scotia-Fundy offshore environment.

FRAMEWORK ASSESSMENT

Framework for Classification of Benthic Habitats and Life-History Traits of Associated Fauna

Classification of benthic habitats on Scotian Shelf is based on the habitat mapping framework developed by Kostylev (2005). The framework adapts Southwood's (1977, 1988) habitat template theory to characterization of seabed environments and mapping of benthic habitats. The framework differs from other habitat mapping approaches by considering the influence of physical environment on life history strategies of species. In this model, habitat properties, and consequently life history strategies of benthic organisms, are thought to be determined by two major forces - durational habitat stability (Disturbance) and the severity of environmental conditions (Scope for Growth).

Within this framework for classification of benthic habitats in the Scotia-Fundy Region, *disturbance* is defined as a purely natural, mechanical force determined by the action of currents and waves on the substrate. *Scope for growth* is related to the energy available for organisms to spend on reproduction and growth, after meeting basic metabolic needs. The physical parameters that are used to characterize disturbance and scope for growth are described in more detail in the following sections.

Habitats where the frequency of physical disturbance is low are classified as "stable" and habitats where the frequency of physical disturbance is high, as "disturbed." Habitats where the scope for growth is high are classified as "benign" or "productive", and habitats where the scope for growth is low, as "adverse." The combination of these characteristics provides a two dimensional habitat template as illustrated in Figure 1.

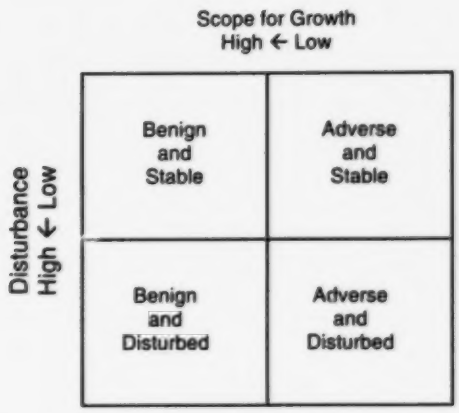


Fig. 1. Characterization of Habitats Based on Disturbance and Scope for Growth.

Benthic communities are understood to consist of a complex mix of species, with a variety of life history strategies. Within each habitat type, one is able to make prediction of the types of species that may be present there (Table 1). For example, benign and stable habitat is predicted to contain species with moderate defense capabilities, limited migration, small to medium sized offspring, moderate longevity, and low tolerance. Adverse and disturbed habitat is predicted to contain tolerant species with good defense capabilities, low migration rates, few and large offspring and great longevity.

	Benign	Adverse
Stable	Defense medium Migration low Offspring medium and small Longevity medium Tolerance low	Defense high Migration low Offspring few and large Longevity great Tolerance high
Disturbed	Defense low Migration high Offspring many small Longevity small Tolerance low	Defense high Migration high Offspring medium large Longevity medium Tolerance high

Table. 1. The relative importance of different life-history strategies in various habitats as predicted by Southwood (1988; Figure 8).

Characterizing Benthic Disturbance in the Scotia-Fundy Region

Natural benthic disturbance occurs as a result of processes such as tidal and circulation currents, storm and internal waves. For the Scotia-Fundy Region, benthic disturbance has been related to the frictional velocity on the seabed and critical shear stress for a given particle size.

Frictional Velocity (Fv)

The friction velocity calculation was the synthesis of four data products: (1) high resolution bathymetry of the region, (2) 42-year hindcast of the wave height and period, (3) near-bottom estimates of tidal current extracted from various models; (4) grain size estimates. These were all used as inputs for the calculation of bottom stress (friction velocity) using the SEDTRANS96 software (Li and Amos, 2001).

Critical current (H)
Critical current is the current velocity required to move a given grain size. For the Scotian Shelf, grain size was interpolated from a database of empirical observations, and then the corresponding critical current for this grain size was derived from the Hjulstrom diagram (Hjulstrom, 1935). An assumption was made that sediments are well-sorted.

Disturbance
Disturbance is calculated as the ratio of the frictional velocity to the critical current according to the following equation:

$$\text{Disturbance} = \log(Fv/H)$$

The resulting values are then scaled for a range of 0-1. A map depicting disturbance across the Scotia-Fundy Region is shown in Figure 2.

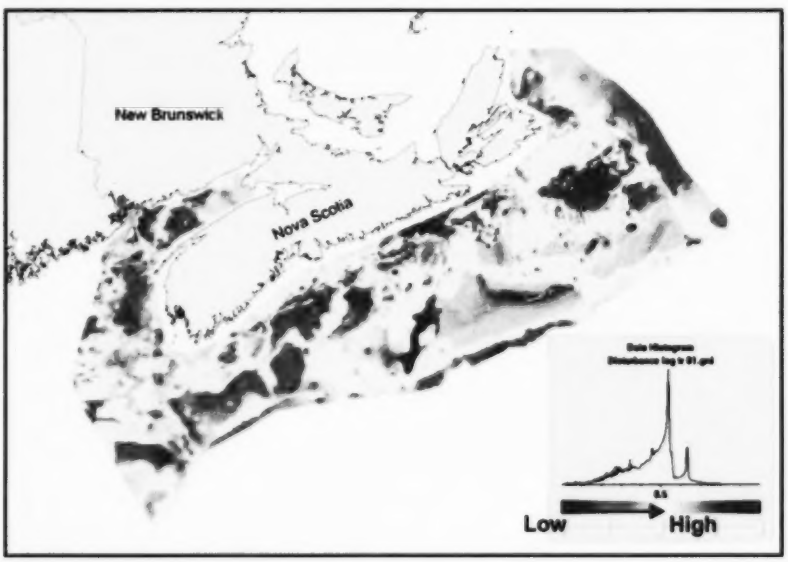


Fig. 2. Disturbance map for the Scotia-Fundy Region. Blue areas are relatively stable, while red areas are relatively disturbed.

Characterizing Benthic "Scope for Growth" in the Scotia-Fundy Region

Scope for Growth refers to the amount of energy in the environment available for an organisms' growth and maintenance of normal physiological functions, i.e. productivity.

It is negatively related to the energy required to adapt to an adverse environment. Scope for Growth is related to the physiological energy equation:

$$\text{Production} = \text{ingestion} - \text{respiration} - \text{excretion}.$$

Every physical parameter included in the determination of Scope for Growth can be related to some component of the energy equation (Table 2).

Components of the Energy Equation	Related Physical Variables
Ingestion	Food availability: chlorophyll a, stratification
Respiration	Average bottom temperature, Seasonal temperature variation, Annual temperature variation, Percent oxygen saturation
Excretion	Salinity [not used, see text]

Table 2. Physical environmental variables assessed for in Scope for Growth.

Since there is no common unit of measure for the five relevant parameters, linear approximation is used to translate the range of values present in the Scotia-Fundy Region into a dimensionless index from 0-1. An example of this is shown in Figure 3.

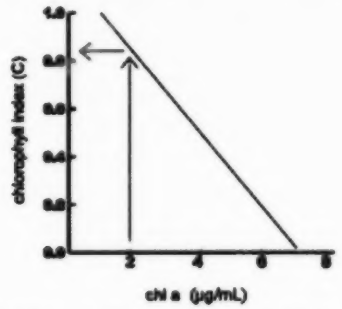


Fig. 3. Example of how measures of chlorophyll a are converted into an index from 0-1.

Food Availability Index (Fa)
Spatially explicit models of benthic-pelagic coupling for the Scotia-Fundy Region are not readily available. As a proxy for the offshore environment, a food availability index has been established as the spring chlorophyll a index minus the summer stratification (sigma-t difference between the surface and 30 m) index. In the coastal environment, macrophytes will also have to be factored into the determinations of food availability. The next version of this index should take into account the relationship between depth and the amount of primary production that reaches the benthos (Hargrave, 2001).

Annual Bottom Temperature Index (Tm)
The relationship between temperature and growth rate has been clearly established, with higher temperatures generally being more favourable in the temperate waters of the Scotia-Fundy Region. In general, physiological processes intensify roughly 2-3 times with every 10 degrees increase in ambient temperature (Leninger, 1975). Average annual bottom temperatures for the Scotia-Fundy Region were determined based on historic records (Breeze et al. 2002, Hannah et al. 2001, Han et al. 1999).

Seasonal and Interannual Temperature Variability Indices (Ta, Ti)
Seasonal and interannual temperature variability can act as abiotic stressors to marine organisms, with increased temperature variability requiring some form of adaptation. For example, seasonal variability may be important for the timing of reproductive activity. Seasonal temperature variability and interannual temperature variability for the Scotia-Fundy Region were

determined based on historic records (Petrie et al. 1996, Breeze et al. 2002, Hannah et al. 2001, Han et al. 1999).

Oxygen Index (O)
Oxygen saturation (%) is thought to play a limiting role in certain areas in the shelf (e.g., basins). Approximately 30,000 measures of oxygen saturation taken from the Scotia-Fundy Region were analyzed, mapped, and then included in determinations of Scope for Growth. Limitations of this data, including its age, lack of depth information, and variations in collection methodology and seasonality, were acknowledged. However, inclusion of oxygen saturation information appears to assist in differentiation of certain benthic community types (e.g. those found in deep basins), and therefore has been included as a component of the Scotia-Fundy benthic classification framework.

Salinity
Salinity (ppm) is known to influence excretion by marine organisms and therefore likely plays a role in scope for growth. However, given the limited range of salinities across the Scotia-Fundy Region and therefore low likelihood for influencing distribution of benthic species, salinity was not included in this benthic classification framework.

Scope for Growth
There is no clear theoretical basis for determining the relative importance of each dimensionless environmental indices to Scope for Growth. The Scotia-Fundy Benthic Classification gives equal weighting to each parameter using the following equation:

$$\text{Scope for Growth} = \log \left[\frac{Fa + Tm - Ta - Ti + O}{5} \right]$$

The resulting values are then normalized on a scale from zero to one. A map depicting Scope for Growth across the Scotia-Fundy Region in shown in Figure 4.

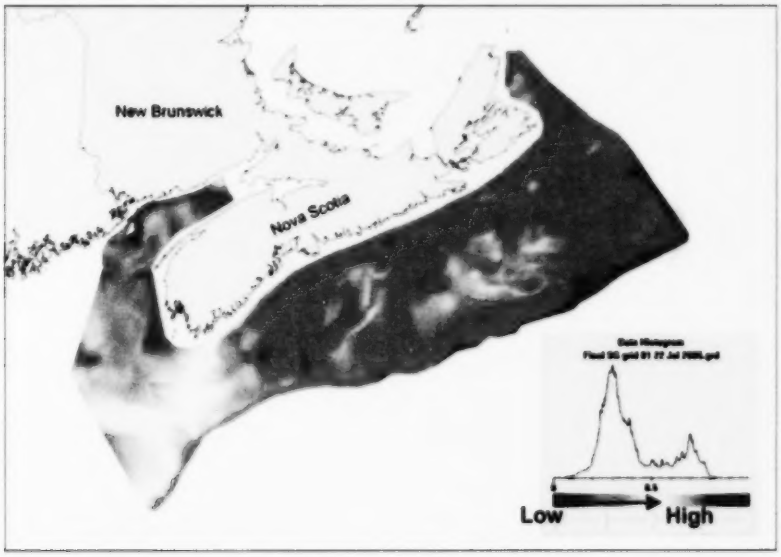


Fig. 4. Scope for Growth map for the Scotia-Fundy Region. Red areas are relatively productive, while blue areas are relatively unproductive (adverse).

Habitats of the Scotia-Fundy Region

Benthic habitat classification for the Scotia-Fundy Region is a function of Disturbance and Scope for Growth. The classification scheme considers each of these as independent axes since there is as yet no theoretical basis for combining them into a single measure. The two independent axes of Disturbance and Scope for Growth are visualized as a benthic classification map using a continuous color scale (Figure 5).

Benthic Habitat = F (Disturbance, Scope for Growth)

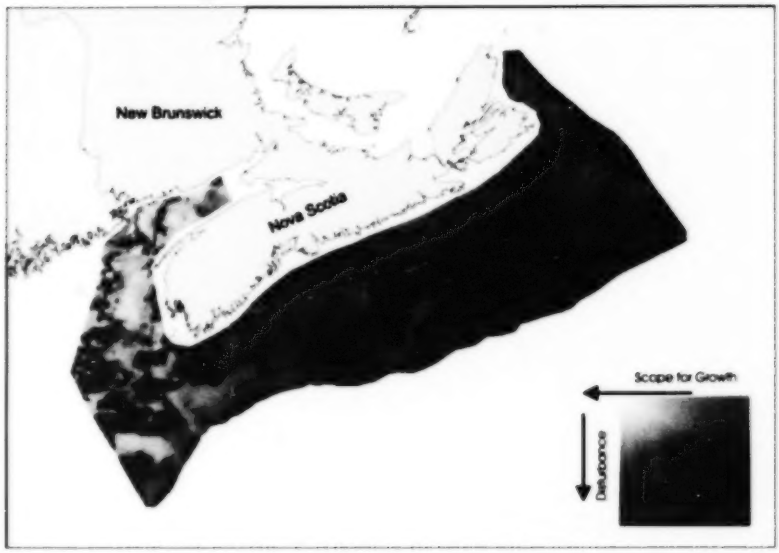


Fig. 5. Classification of Scotia-Fundy Benthic Habitat.

This approach produces a continuum of habitat types bounded by the extremes of Disturbance (disturbed to stable) and Scope for Growth (adverse to productive).

Defining Sensitivity

While the classification scheme for benthic communities in the Scotia-Fundy Region improves our understanding of and ability to depict the interaction between the physical environment and biological communities, additional theory is needed to demonstrate how it might be used for management purposes. An important question from management is what does this model tell us about the potential sensitivity of benthic communities to human disturbance.

Sensitivity is defined here as a function of the recoverability and the vulnerability of some biological component, such as a community, species, or population. Vulnerability refers to the likelihood that a component will be exposed to some impacting factor. Vulnerability is related to the condition and properties of a component, including body size, shape, and structure, which may influence its susceptibility to impact. For example, large, exposed organisms may be more vulnerable to impact than small, buried organisms. Recoverability refers to the rate at which a component is able to return to some previous state after being impacted. Recoverability can be determined empirically or through known or suspected life history traits, such as fecundity, longevity, and mobility.

How Sensitivity Relates To The Benthic Classification Model

Based on the previous definition, a highly sensitive benthic community is one that has high vulnerability to and low recoverability from an impact. A low sensitivity benthic community is one that has low vulnerability to and high recoverability from an impact. The relationship between the sensitivity and the life-history strategies of organisms is not clearly defined. However, it is expected that K strategists, i.e. those species with long life expectancy, late maturity and few offspring, would likely be more sensitive to human disturbance than r strategists. A benthic community is composed of populations of individuals, each with its own sensitivity to an externally motivated change or impact (natural or anthropogenic). The aggregate of these sensitivities is expected to define the overall sensitivity of that community.

Vulnerability is related to an organism's physical structure, such as shape and size. Disturbance is defined here as a mechanical force and is related to shear stress at the bottom. For benthic communities, then, there is clearly some relationship between Disturbance and Vulnerability in terms of the impact of mechanical force upon body structure. Recoverability was previously described as being linked to reproduction, growth and mobility, while Scope for Growth is determined by the energy available in the environment for reproduction, growth and adaptation. There is thus some relationship between Recoverability and Scope for Growth. Each of these relationships (i.e. vulnerability and disturbance, recoverability and scope for growth) are expected to be quite complex, and neither have been fully characterized. However, for the purposes of facilitating current ocean management, the parameters of Disturbance and Scope for Growth used to characterize benthic communities may also be used to characterize the sensitivity and predicted response of benthic communities to human impact (Figure 6).

Scope for Growth
High ← Low

Disturbance High ← Low		
	High recoverability and High vulnerability to physical disturbance After disturbance, a community may recover quickly, but it may go through a number of semi-stable states and end up with a different species composition. Example: Bank top gravel habitats, such as the gravel lag on Georges Bank.	**Low recoverability and High vulnerability to physical disturbance** After disturbance, the community may slowly come back to the similar state. Some species may be lost because some populations may not recover Example: Deep sea coral communities.
	High recoverability and Low vulnerability Communities are likely to recover quickly from disturbance and return to a similar state. Example: Communities dominated by scavengers and mobile species, such as on tops of banks.	**Low recoverability and Low vulnerability** Communities, while highly resistant to disturbance, will likely take a long time to recover once disturbed. Example: Slow growing species tolerant to physical disturbance, such as quahog communities on Banquereau Bank.

Figure 6. Predicted response of different benthic community types to (primarily physical) disturbance.

CONCLUSIONS AND ADVICE

The strength of the approach is in using natural conditions of the environment as a reference point to evaluate human impacts. The proposed benthic classification scheme is a significant conceptual advance accounting for potential human-habitat interactions. The model can help

managers understand complex interactions between physics, chemistry and biology and thus lead to greater appreciation of the ecological consequences of human impacts. This framework for benthic characterization:

- Provides a theoretical basis that can be validated using observations.
- Organizes thinking on how benthic communities function and are distributed.
- Provides a structured way of evaluating sensitivity of habitats to human impacts.
- Facilitates research prioritization.

OTHER CONSIDERATIONS

Sources Of Uncertainty

There are numerous sources of uncertainty inherent in this Benthic Habitat Classification for the Scotia-Fundy Region, including uncertainty in the validity of the theoretical basis for the framework (i.e. defining habitats based on the two axes of Disturbance and Scope for Growth), uncertainty in the selection and relative importance of environmental variables used to define Disturbance and Scope for Growth, uncertainty in the quality of data available for the Scotia-Fundy Region, uncertainty in the interpolation of empirical observations across time and space, and uncertainty in the appropriate visualization of the results (i.e. in terms of color scaling, etc.).

Validity of the Disturbance / Scope for Growth Model
Initially proposed by Southwood (1977,1988), numerous other investigators have observed and published results showing the importance of both Disturbance (also referred to as Turbulence, Processing Constraints, etc.) and Scope for Growth (also referred to as Adversity, Nutrients, Rate of Growth, or Resource Constraints) for distribution of species (Margalef et al., 1979; Huston, 1979; Reynolds, 1999; Roff et al., 2003). The similarity of results across of wide range of species groups is encouraging, however, further testing of the specific role of Disturbance and Scope for Growth in determining distribution of benthic communities in the Scotia-Fundy Region is required.

Selection and Relative Importance of Environmental Variables
The current measure of food availability indicates the general pattern of primary production availability at the seafloor but does not incorporate horizontal transport processes. In the future, experimental measures of carbon loading to the benthos at various points across the Scotian Shelf may provide a more complete measure of food availability. It is expected that further refinements would be likely to improve the visualization of fine-scale variability across the Scotia-Fundy Region but would not change the overall pattern of Disturbance and Scope for Growth.

Quality of Relevant Data for the Scotia-Fundy Region
Wide-spread, consistent monitoring of biophysical variables across an area as large as the Scotia-Fundy Region is rare. While efforts were made to ensure the quality of data used, the overall spatial coverage of data varies for each parameter. For example, measures of percent oxygen saturation have poorer spatial and temporal coverage than measures of bottom temperature. This framework only incorporates natural sources of seabed disturbance. However, it is possible that some of the parameters (e.g. grain size) may have been influenced by anthropogenic activities and may not be representative of natural disturbance conditions.

Interpolation of Results
A large source of uncertainty is the interpolation of variable fields from empirical observations aliased in space and time. The underlying data layers have spatial accuracy on the order of a few kilometres to a few tens of kilometres. The current map assumes homogeneity within a 500m grid. However, this generalization is necessary because higher resolution information is not available for the whole shelf.

Validation of Sensitivity Analysis
More work is required to demonstrate how the proposed benthic classification scheme could be used to assess the sensitivity of various benthic habitats to human activity. For example, it will be useful to overlay maps of known distributions of sensitive species on the empirically derived physical data. Other validation exercises should also be undertaken. Validation exercises should consider that this is a model of predominantly natural, not anthropogenic disturbance.

Management Considerations

The benthic habitat model is a practical tool that will assist with oceans planning and management activities. By capturing emergent properties of the Scotian Shelf benthic ecosystem, the approach serves as a key component of both objectives-based and ecosystem-based planning and management. When combined with other information, in particular mapping of Ecologically and Biologically Significant Areas (DFO, 2004d) and distribution of sensitive species, the model can provide the basis for determining appropriate management actions to meet established ecosystem objectives. The ecosystem objectives proposed for the Scotian Shelf are outlined in the draft Eastern Scotian Shelf Integrated Ocean Management Plan (2006-2011) (DFO, 2005). There are a range of management tools to assist in meeting these objectives, such as seasonal restrictions on activities (e.g., fisheries or other closures), marine environmental quality guidelines, activity-based zoning, and industry protocols.

As indicators, reference points and targets are developed through the collaborative planning framework of ESSIM, the benthic habitat model and associated maps will provide an important added layer of information. While the model does not provide exact species distribution, it gives a broad and systematic view of expected life history traits and community characteristics analogous to climatic zone maps used in agriculture. Additionally, it has been shown that the individual data layers developed through the model are also useful guidance tools for management. The model and the maps produced provide a significant advancement in the identification of habitat types and associated community structures that will ultimately lead to more effective achievement of both ecosystem and human use objectives for the Scotian Shelf.

Effective application of this benthic classification framework for the Scotian Shelf will require due consideration of its intended scope. While the framework will contribute valuable information to many management scenarios and questions, it is not expected to be used as the sole source of information for decision-making. For example, the following constraints should be taken into consideration:

- The focus of this model is on physical impacts to benthic invertebrates. This framework will not be readily applicable to management questions related to chemical and biological impacts or pelagic communities.

- The framework does not provide an explicit measure of uncertainty within each calculation of disturbance and scope for growth. While a generalized explanation of the uncertainty

inherent in the model is provided above, specific measures of uncertainty at each point on the map are not provided.

- No guidelines or definitions have been established to delineate one benthic community type from another. Maps show gradations of color rather than strict boundaries to separate community types.

- The scale of analysis is 500 x 500 m squares. The framework will not be applicable to management questions that require differentiation of benthic communities at smaller scales.

- Characterization of disturbance does not include a temporal component at this time, i.e., the frequency of significant disturbances is not captured, nor is the temporal variability of disturbance.

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